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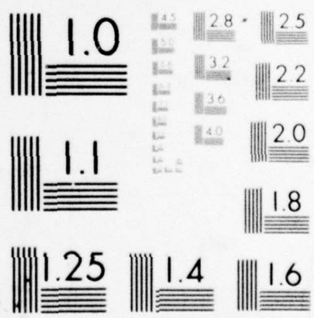

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PRESENT STAGE OF DEVELOPMENT AND PROSPECTS FOR FUTURE DEVELOPMENT OF SHIPBOARD POWER PLANTS ON SEAGOING TRANSPORTS

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This article deals with the present stage of development of power plants found on seagoing transports and likely trends in the development of different types of main power plant in the immediate future. The article is based on materials drawn from a study of the characteristics of modern power plants currently in use in Soviet and foreign maritime fleets and trends in the development of various types of power plant. [3*

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Present-day deyelopment of seagoing transports is marked by ever-increasing speed and cargo capacity and this enhances the importance of shipboard power plants among the indicators of technical and cost effectiveness of operation. During the past seven years alone the average tonnage of vessels in the domestic fleet has increased by about 40%, ship speed by about 20%, and the power of the main engines by about 90%. The increase in power of main engines has led to the cost of a power plant accounting for 35% of the overall cost of construction and the cost of fuel for 40--45% of overall operational cost of a vessel. The cost of fuel is this much higher regardless of the fact that economical new power plants are installed for which the weighted average specific fuel consumption per unit of power of a main engine on a transport has dropped during the past seven years by about 35%.

The principal types of engine used on seagoing transports are diesels and steam turbines and during the past ten years the emphasis has been on diesels which are now being used over an ever-increasing horsepower range. According to statistical data published by Lloyds of Britain vessels with a deadweight tonnage of 2000 *T* and over powered by diesel engines constituted in 1965 57% of all vessels and 50.8% of the total deadweight tonnage worldwide while in 1962 they accounted for 52.6% and 45.5% respectively and in 1959 43.5% and 39.5%. The percentage of diesel powered vessels on order is constantly increasing. While in 1959 of all the transport vessels of 2000 *T dwt* or more being built on ways worldwide diesel powered vessels accounted for 85.7% of the number of vessels, 65.7% of the deadweight tonnage, and 71.5% of the total engine horsepower, in 1965 they accounted for 90.1%, 78.2%, and 79.2% respectively. The power limit for preponderant employment of diesel engines as main engines shifted from 12,000--13,000 *HP* in 1959 to 15,000--16,000 *HP* in 1965 and diesel-powered vessels already built or being built include many large-tonnage vessels whose main engines

* The numbers in the right margin indicate pagination in the original text.

produce a total of about 25,000 *HP*.

Over the past few years the domestic maritime fleet has developed as to type of power plant along the same lines as the worldwide maritime fleet. While in 1959 diesel-powered vessels accounted for 52.5% of all vessels in the maritime fleet, in 1963 they accounted for 65.2% of all vessels and 62.5% of total deadweight tonnage. At the beginning of 1965 diesel-powered vessels accounted for 70.2% of all vessels, 64.7% of all deadweight tonnage, and 70.9% of the total horsepower output of the main engines. Diesel-powered vessels carried 69% of all cargo. [4

The principal type of main internal combustion engine installed on new vessels has been the reversible, two-stroke, crosshead, single-acting, low-speed diesel which is turbocharged and delivers its output directly to a propeller. The engine most frequently installed is the "Burmeyster and Vayn" with uniflow scavenging and the "Zul'tser" with cross scavenging. Much less frequently installed has been the MAN (loop scavenging) and the "Fiat" (cross scavenging). The rated power per cylinder of most engines is 540--2100 *BHP* with a total engine power of 2900--18,900 *BHP* and rate of rotation of the propeller shaft of 115 to 170 *rev/min*. The average effective cylinder pressure is 6.5--8.6 kg/cm^2. The specific fuel consumption of a main engine is 157--165 *g/BHP-hr* and the overall specific consumption of a power plant 175 *g/BHP-hr*. The lubricating oil consumption (cylinder and cooling) is 0.6--1.1 *g/BHP-hr*. The specific weight of a diesel power plant is about 90 *kg/BHP-hr* and about 50% of this weight is accounted for by the main engine. The engines are designed to operate on heavy fuel (viscosity up to 40° *VU* [relative viscosity] at 50°C), however most diesel-powered vessels are provided with systems for preparing motor fuel. As of the present time most diesel-powered vessels burn diesel fuel, the relative consumption of motor fuel on diesel-powered vessels not exceeding 15%.

Many of the large-tonnage dry and liquid cargo transports being added to the maritime fleet are domestically built vessels powered by steam turbine power plants in which the main engines are geared turbines producing 13,000 and 19,000 *BHP* with the propeller shaft rotating at 100 and 110 *rev/min* respectively. These power plants, which in principal characteristics are typical of foreign vessels as well during the period under discussion, use steam with initial parameters (in front of the turbogear nozzles) of 40.5 *atm* and 465°C and a condenser pressure of 0.05 *atm*. The specific fuel consumption for all power plant needs (converted to lowest working heat of fuel combustion of 10,000 *kcal/kg*) is 231--243 *g/BHP-hr* and the steam boilers of these plants are intended to burn heating mazuts with a

viscosity of 80° *VU* at 50°C. Their specific weight is 55.5--61.5 *kg/BHP-hr*.

Furthermore, vessels with new types of power plant are being added to the maritime fleet. The Lenin, the first atomic icebreaker in the world, which has a steam turbine power plant and water-cooled reactors, is now in successful operation. Several timber carriers equipped with gas turbine power plants and free piston gas generators of the GS-34 type manufactured by the "Sigma" firm with a rated power of 4000 *BHP* at 115 *rev/min* have been built. The specific fuel consumption of these power plants which were intended to burn motor fuel and light mazut but actually burn diesel fuel primarily is 200--205 *g/BHP-hr*. The specific weight of the power plant is 61.5 *kg/BHP-hr*. The first vessel with a turbocompressor gas turbine producing 13,000 *BHP* the power from which is transmitted to a variable pitch propeller through a two-stage reduction gear has been built domestically. The rate of rotation of the propeller shaft is 100 *rev/min* and the initial temperature of the gas [5
750°C. The specific fuel consumption of this power plant equipped with a special system for fuel preparation in order to burn motor fuel and light mazuts is about 225 *g/BHP-hr* and the specific weight of the plant is about 55 *kg/BHP-hr*.

Continuing development in the application of low-speed diesels as main shipboard engines in maritime fleets world-wide over the past ten years has been due to the great progress made in building ship diesels so as to achieve a much greater power output (by improving supercharging and the size of cylinders) along with improving the reliability of the main parts of engines and due also to the possibility of burning heavy residual fuels with a higher sulfur content (by using special systems for fuel preparation, high-alkali cylinder oils, and improvements in design).

Transition to the use in low-speed diesels of fuels with a higher viscosity (about 16--20° *VU* at 50°C) has led in foreign practice to a sharp reduction in the cost of fuel inasmuch as these fuels are on the average 40--50% cheaper than diesel fuel, approaching the cost of the fuel used in the boilers of steam turbine plants (by changing the viscosity from 16--20 to 40--60° *VU* at 50°C the relative cost drops by only 10--11%). In our country with the existing relative fuel prices, that is, a difference between the prices of diesel and motor fuel of about 8%, the cost of bunkering included, and a difference in the prices of motor fuel and heating mazut of about 15%, using fuel heavier than DT-1 motor fuel in shipboard diesels is economically unsound. Steam turbine mazuts with an ash and foreign matter content 2--3 times higher than in foreign fuels with the same viscosity are put in an unfavorable position with respect to the main item of operational cost of

seagoing vessels.

The selection of type of power plant for a seagoing transport is determined by many factors which have an important influence on the prime cost of shipments and the construction cost of a vessel and take into account the overall indicator of reduced expenditures. The most important of them are the type of fuel and consumption of it, cost of manufacturing the power plant, cost of maintaining the engine room crew, and the average length of time annually the vessel is kept out of operation for the purpose of repairing the power plant. Weight and size indicators of power plants have much less influence on the indicator of reduced expenditures than the factors listed above.

Numerous comparative technical and economic calculations performed for turbine and diesel power plants built in 1960--1966 based on the costs prevailing in our country and the relative influence of different factors on the reduced cost indicator show that in the range of power of a main engine of 10,000--12,000 *HP* diesel and steam turbine power plants are practically equal in cost and the selection of one type of power plant or the other must be based on the purpose of the vessel, conditions of operation, and the possibility of delivering a well-proven main engine which will provide sufficient power.

At lower levels of engine power it is undoubtedly advisable to use as main engine a low-speed diesel while at a level of 4000--5000 *HP* a gas turbine with a free piston gas generator is a good competitor. At higher power levels steam turbines show the best economic indicators. For example, for the power plant on a dry cargo vessel displacing about 22,000 *T* whose main engines produce 13,000 *BHP* an ordinary steam turbine plant (with initial steam parameters of 40.5 *atm* and 465°C) burning sulfurous mazut, in distinction from a diesel power plant burning motor fuel, has indicators better by 7.8% in prime cost of shipments and by 10% in specific capital investment based on fuel prices in a price list in effect. At prices for fuel less the turnover tax, following the method recommended for determining the type of power plant to be employed based on technical and economic factors, the prime cost of shipments for a vessel equipped with a steam turbine is less than for a vessel with a diesel power plant by 17.7% and the reduced cost indicator less by 14.3%. [6

It is impossible as yet to compare similarly a gas turbine turbocompressor power plant with other types of power plant because of lack of experience in operation, this preventing confident evaluation of the possibility of burning cheap fuels and the reliability of such power plants in operation. Power plants with atomic reactors for transports are not com-

petitive with conventional power plants at the present time because of the high cost of the fissionable materials used in reactors and construction costs.

At the present time development and improvement of all types of power plant on seagoing transports are marked by close competition between two types of main engine--the low-speed diesel with direct power transmission to the propeller and a steam turbogear unit. The principal general trends in the development of power plants aimed at improving the operational and economic indicators of transports are:

a) raising the thermal efficiency of power plants and burning cheaper fuels in order to reduce fuel consumption and fuel costs;

b) improving the reliability and life of power plant equipment in order to reduce the labor required for maintenance and to reduce nonproductive losses in carrying capacity of vessels due to the need to take them out of operation for repair, this being especially important in connection with the higher thermal intensity and greater complexity of power plants (due mainly to the effort to improve fuel economy) which inevitably entail lower reliability;

c) automation of power plants (including remote monitoring and control) providing firstly for a reduction in the labor (and consequently manning tables) expended by an engine room crew in monitoring and controlling processes and secondly for improved economy of operation as a result of optimizing modes of equipment operation and holding the level of principal parameters more stable;

d) a rise in absolute and specific power output of power plants leading to improvement in their weight and size specifications, ship speed and carrying capacity both increasing.

Trends in the development of diesel power plants lead to the conclusion that the main engine in them will remain the low-speed diesel. The cylinder power of these engines is being improved, this being accomplished by improving the scavenging process and increasing the size of the cylinder somewhat. It can be expected that in the next 5--7 years the average effective pressure will be increased to 12 kg/cm^2 and the cylinder power to 3000--3300 *BHP* and that engines with a cylinder diameter of more than 900 *mm* will not find wide use.

Apparently the thermal efficiency of shipboard diesels will remain at the level now achieved, the possibility of improving the working process being very limited and an increase [7
in the degree of supercharging entailing some increase in fuel consumption. As far as diesel power plants as a whole are concerned, their economy will improve greatly and in the main modes of operation of vessels with relatively powerful engines (8000--9000 *BHP* and higher) the specific fuel consumption of

a power plant will approach or reach that of the main engine. This increase in economy of operation (mainly on tankers and bulk cargo carriers which stay over in port only briefly) will be achieved by thoroughly utilizing the heat from exhaust gases in utilization boilers for providing steam to a turbogenerator powerful enough to meet all the electrical needs of a vessel and also by utilizing the heat of engine coolant in shipboard evaporators, air conditioning systems, etc.

The cost of fuel for main shipboard low-speed diesels can be greatly reduced by switching them to high-viscosity fuel (up to 20° *VU* at 50°C) such as light mazuts. As research performed at the TsNIIMF [Central Scientific Research Institute of the Maritime Fleet] shows, the use of such fuel will be economically well founded when the difference between its price and that of motor fuel DT-1 is 4--5 rubles per ton. The absence of important limitations on sulfur content in high-viscosity fuel for low-speed shipboard diesels is due to the use of special high-alkali cylinder oils in amounts per unit engine power which are high compared with established standards. This gives good reason to expect a greater reduction in cost of such fuel as compared with motor fuel.

One important way to increase the efficiency of diesel power plants is to improve their auxiliary equipment by effecting possible reductions without impairing reliability in the number of mechanisms and heat exchangers, using multi-purpose units, selecting the most economical and reliable designs for mechanisms and apparatuses, and also improving its arrangement and location in the engine room.

The principal and most effective way to improve diesel power plants is to improve the reliability (extend breakdown-free operation and service life) of the main and auxiliary diesels. A realistic expectation for the near future is to extend the duration of operation of the main engines between cleanings to 6--8 thousand hours and between minor repairs to 16--18 thousand hours and to extend the time between servicings of injectors to 6000 hours. Of great importance in improving the reliability of main diesels is designing them well for sustained output in all modes of operation without overheating parts in the cylinder-piston group.

Such an increase in the reliability of a main engine accompanied by an increase in the duration of breakdown-free operation of auxiliary equipment will make it possible to eliminate watches in servicing a diesel power plant by automating monitoring and control of components which have been made ready for operation.

Two important problems in improving the efficiency of

shipboard diesel power plants are reducing the number of revolutions of a main engine which transmits its power directly to its propeller for the purpose of improving the propulsive efficiency of the propeller and greatly improving the reversing capability of powerful diesels on large-tonnage vessels for the purpose of achieving an acceptable maneuvering capability.

The improvements being made in shipboard steam turbine power plants which have now entered into a new phase of development are mainly along the line of raising thermal efficiency while providing for a high level of reliability of primary and auxiliary [8 equipment, decreasing overall dimensions of engine and boiler rooms, and extensively automating monitoring and control so as to achieve a significant reduction in engine room manning tables.

The improvements being made in conventional steam turbine power plants (single-acting) are along the lines of:

a) raising the initial parameters of the steam to 60--70 *atm* and 510--535°C;

b) raising the efficiency of boilers (by lowering the temperature of departing gases by using regenerative air heaters and lowering the excess air ratio by installing better combustion chambers);

c) raising the efficiency of main turbines (by improving passages) and auxiliary mechanisms;

d) improving thermal system economy (by driving shipboard electrical generators and feed pumps from the turbogear shaft or by using a turbogear take-off to drive auxiliary turbines for the condenser or to establish a counterpressure for heating feed water);

e) improving the degree of regeneration in a cycle and making other technological improvements.

Of great interest are the foreign power plants and plans for them with new ("single-plan") arrangement of the main turbogear assembly which make it possible to greatly (up to 20%) reduce the length of the engine and boiler rooms. They have one main and one auxiliary ("emergency") boiler with a planetary reduction gear, making it possible to achieve a significant reduction in revolutions and to increase the propulsive efficiency of the propeller. They also have boilers with their combustion chambers overhead and other features. Such units have yielded a specific fuel consumption on the order of 205--210 *g/BHP-hr* (at a fuel combustion heat of 10,000 *kcal/kg*).

The operation of steam turbine power plants can be made more economical by improving their cycle (at the same time implementing the improvements mentioned above) through the use of intermediate reheating of the steam and combined steam and gas power plants. With the initial steam and gas para-

meters most probable in the near future and degree of rise in pressure in a gas turbine plant the magnitude of specific fuel consumption in a power plant can be about the same for a power plant with intermediate reheating and for a steam-gas plant and equal to 180--190 *g/BHP-hr*. In light of the more rigid demands a gas turbine power plant makes of the fuel it uses as compared with a steam turbine plant, the difference in fuel prices, and also the extensive experience acquired in manufacturing reliable steam turbine power plants, it should be expected that the latter will be given preference.

A typical steam turbine power plant which will be developed in the near future will be one with initial steam parameters of 65--80 kg/cm^2 and 510--535°C, one intermediate reheating of the steam to the initial temperature, and a complete system for regenerative (4- or 5-stage) heating of the feed water. The shipboard electric generator and feed pump will be driven by the main turbine assembly in the main modes of movement. The main turbine assembly, with a toothed gear transmission of power to the propeller, will have a rate of rotation of 85--90 *rev/min*. Intermediate heating of the steam will be accomplished in the gas steam superheater of one of the two main boilers which are equipped with combustion chambers ensuring a minimum excess air and rotating air heaters. The efficiency of the boilers will be increased by 94--95%. The specific fuel consumption for such a power plant producing 20,000--25,000 *BHP* will be about 180 *g/BHP-hr* which in light of the possible reduction [9
in revolutions of the propeller will make it possible for a steam turbine plant to closely approach a diesel plant in specific fuel consumption on the work done by a vessel in transporting a cargo.

The degree of automation of steam turbine power plants will reach a level such that watches will not be necessary to service them and the main turbogear assembly will be controlled from the bridge. The level of reliability of main power equipment required for this can be considered to be already achieved.

The development of gas turbine plants for transports in the near future will be marked by a rise in the reliability of the main components and mastery in burning heavy commercial fuels. The rise in initial temperature of the gas will be limited to 800--850°C. Efficiency will be enhanced by improving the gas-dynamic characteristics of turbines and compressors and their passages. A realistically achievable specific fuel consumption for a gas turbine plant can be set at 180--190 *g/BHP-hr*.

The use of nuclear energy in the power plants of transport vessels, as formerly, is limited to test models and to a search for solutions which will make nuclear steam-producing power

plants competitive with conventional ones as to principal technical and economic indicators.

In evaluating the prospects for installing the different types of power plant in transport vessels in the near future it should be observed that diesel and steam turbine power plants, as formerly, will remain the main ones and primary use will be made of steam turbine plants in which the main engines will generate great power. The technical and economic feasibility of installing one type of main engine or another is determined first of all by relations between such indicators as fuel cost and crew maintenance, the construction cost of power plants, expenditures on preventive maintenance, repair of power equipment, and the duration of power plant repair in shipyards. In connection with the fact that the relation between items of operational expenditures are far different in domestic practice from that in foreign practice, it is apparent that the technical and economic feasibility boundary in the use of diesel and turbine power plants will also differ in our case and, based on preliminary estimates, will fall within a range of main engine power of 10,000--15,000 *BHP* (depending on the purpose of the vessel and cruising area). The following points should be kept in mind when making such an estimate.

It is known that in cost of construction a modern diesel power plant in the indicated range of power has indicators about 40--50% inferior to those of a steam turbine plant. It should be borne in mind that the latter can be kept in constant operation at rated power and a main ship's diesel under average conditions of operation should, for the purpose of preventing thermal overload, be operated at a load no greater than 85--90% of rated.

With respect to the important indicator of a ship's effectiveness of length of time it is kept out of operation for shipyard repair, vessels with steam turbine power plants also have an advantage over diesels thanks to their greater reliability and greater time of operation between performances of preventive maintenance.

At the same time, since with respect to the total amount of work involved in preventive maintenance and repair of vessels the proportionate share of work devoted to the power plant does not usually exceed 25%, it should be considered that when maintenance is correctly organized the average annual time a dry cargo vessel is in operation will be practically the same [10 regardless of the type of power plant installed on it. For tankers, whose duration of stopover in port is insufficient for performing preventive maintenance on the main engines, the average operational period will be 5--8 days longer than for vessels powered by steam turbines.

Inasmuch as in domestic practice fuel costs constitute the main item in the operational expenditures for a vessel, the prices paid for fuel have a very great influence on comparative technical and economic indicators for different types of power plant. The prices of fuel in effect at the present time do not reflect their actual value and unconditional reliance on them can lead to a mistaken conclusion as to the greater feasibility of processing the heavier grades of fuel which are suitable for use in diesel engines under shipboard conditions (using complex and expensive fuel preparation systems) rather than at fixed facilities.

It can be expected that a review of the prices paid for petroleum products will lead to a sufficiently accurate evaluation in the consideration of fuel costs of its qualitative characteristics (foreign matter, ash, and sulfur content), the economic value of a petroleum product, and the labor required to produce it. As a result, there will be an increase in the difference in price paid for heavy residual boiler fuels used without additional processing in steam turbine power plants and for high-viscosity fuels (light mazuts) which are used in low-speed diesels, the systems used for fuel preparation for which are relatively simple.

A comparative estimate of the technical and economic effectiveness of one type of power plant or another as far as fuel consumption is concerned must, apparently, be made with respect to specific fuel consumption per unit of power usefully expended on moving a vessel in distinction from the initial porposition observed up to the present time to the effect that for a given vessel speed is determined only by the power produced by the main engine regardless of type (that is, not considering the effect of number of revolutions of the propeller shaft on propulsive efficiency). When the evaluation is correct the relation between specific fuel consumptions for diesel and steam turbine power plants will change significantly in favor of the latter since they transmit power to a propeller at a lower number of revolutions.